Proposed TPS-75 site near WSR-88D at Memphis, TN.

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Background

On September 26th, the 728th ACS from Eglin AFB, FL contacted the Radar Operations Center (ROC) regarding a proposed TPS-75 site in close proximity to the Memphis, TN WSR-88D. The 728th ACS requested information regarding potential interference by the TPS-75 to the WSR-88D.

The pertinent parameters for the TPS-75 and WSR-88D are as follows:

WSR-88D Antenna Beam Center	115.217 m MSL
WSR-88D Frequency	2820 MHz (.1063 m wavelength)
WSR-88D Power	750 kilowatts peak (1-2 dB waveguide loss from transmitter to antenna)
WSR-88D Antenna Characteristics	8.53 m parabolic dish (pencil beam) 45 dBi gain (typical) 0.96° beamwidth (3dB; typical)
WSR-88D Elevation Cuts	0.5 to 19.5 degrees
TPS-75 Height	93.5 m MSL
TPS-75 Frequency	3050 MHz
TPS-75 Power	2.8 MW
TPS-75 Transmission Characteristics	PRF: 235, 250, 275 ± .5 Hz 6.8 µs Pulse width
TPS-75 Antenna Characteristics	36 dBi gain 1.1° horizontal, 1.55°- 8.1° vertical 6.5 RPM scan rate 3.35 m high by 5.588 m wide (18.7m^2)
TPS-75 Elevation Angles	0.5 to 20 degrees

The TPS-75 is 1493.5 m from the WSR-88D. The bearing is unknown at this time. Sgt Kaulley from the 728th ACS indicated the transmitter on the TPS-75 is identical to the TPS-43.

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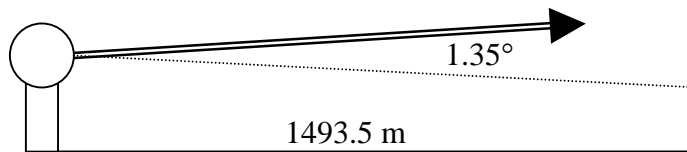## *Impact of Tower on Radar Performance*

Figure 1 – Angle to TPS-75 from WSR-88D Mainbeam

From the information provided, the TPS-75 structure will be below the main beam of the WSR-88D as seen in figure 1. There will be no main beam blockage (defined at 3dB points of antenna pattern) by the TPS-75 antenna and support structures, thus there will be no noticeable effect on weather returns to the WSR-88D resulting from beam blockage.

The power reflected by the TPS-75 antenna and structures must also be accounted for. From the parameters in section 1, the WSR-88D Effective Radiated Power (ERP) is calculated with equation 2-1:

$$ERP = P_t g \qquad (2\text{-}1)$$

ERP = Effective Radiated Power, in Watts
P_T = Transmitted Power, in Watts
g = Antenna gain in relation to isotropic antenna, unitless

The antenna gain, G, of the WSR-88D is given by Equation 2-2:

$$G = 38.43 + \left(\frac{2.5667 f_0}{1000} \right) \qquad (2\text{-}2)$$

G = Antenna Gain, in dBi
f_o = Frequency, in MHz

The gain of the antenna at the site frequency as given by equation 2-2, is 45.68 dBi. Converting this to a unit less ratio and using equation 2-1, the ERP of the WSR-88D is 2.774E10 watts or 134.4 dBm. Adjusting this by an expected 1.5 dB waveguide loss (due to the height of the WSR-88D tower), the ERP is 132.9 dBm.

The boundary of the near-field of the WSR-88D antenna is calculated with equation 2-3:

$$R = \frac{2D^2}{\lambda} \qquad \text{(2-3)}$$

R $\;=\;$ Range of near-field boundary, in meters
D $\;=\;$ Diameter of Antenna, in meters
λ $\;=\;$ Wavelength, in meters

Using equation 2-3, the near-field ends at 1369 m, indicating that the TPS-75 is located 124 m inside the far-field of the WSR-88D antenna.

The elevation angle from the WSR-88D to the TPS-75 is 1.35° below the antenna boresight when the WSR-88D is scanning at the lowest elevation angle. Therefore, there is a significant reduction in the ERP at this angle. The reduction in power is calculated by determining the off-axis gain relative to the boresight using equation 2-4 [2]:

$$G(\theta,\phi) = \exp\left(-\frac{\theta^2 + \phi^2}{2(\sigma_{\theta,\phi})^2} \right) \qquad \text{(2-4)}$$

$G(\theta,\phi)$ $\;=\;$ Relative off-axis antenna gain, unit less ratio
θ $\;=\;$ Azimuth angle from beam axis, in degrees
ϕ $\;=\;$ Elevation angle from beam axis, in degrees

Where σ, the standard deviation of the antenna pattern, is given by equation 2-5:

$$\sigma = \frac{\theta_3}{\sqrt{8\ln 2}} \qquad \text{(2-5)}$$

σ $\;=\;$ Standard deviation
θ_3 $\;=\;$ 3 dB beamwidth, in degrees

Where θ_3 , the 3 dB beamwidth [3], is given by equation 2-6:

$$\theta_3 = 1.595 - \left(\frac{0.243667 f_0}{1000} \right) \qquad \text{(2-6)}$$

θ_3 $\;=\;$ 3 dB beamwidth, in degrees
f_0 $\;=\;$ WSR-88D frequency, in MHz

The relative off-axis gain for the WSR-88D is found by combining equation 2-5 with 2-6 and using the result in equation 2-4 with the following values:

$$\theta = 0° \text{ (assumes both antennas are pointed directly at each other)}$$
$$\phi = 1.35°$$
$$\theta_3 = 0.908°$$
$$\sigma = .385592$$

Therefore, the relative gain of the WSR-88D antenna at 1.35° (at the site frequency of 2820 MHz) is -26.61 dB. The ERP of 132.9 dBm then becomes 106.29 dBm when viewed from a 1.35° angle of depression from the WSR-88D main beam.

The power density at the TPS-75 from the WSR-88D is then calculated with equation 2-7:

$$P_d = \frac{ERP_{\theta,\phi}}{4\pi R^2} \qquad (2\text{-}7)$$

$$P_d = \text{Power Density, in Watts/meter}^2$$
$$ERP_{\theta,\phi} = \text{Effective Radiatied power at angles } \theta \text{ and } \phi, \text{ in Watts}$$
$$R = \text{Range, in meters}$$

The power density at the TPS-75 is calculated to be 1.518 W/m^2 .

Even if the structures and antenna pattern of the TPS-75 were known, the reflections associated with the equipment are highly dependent on variables such as angle to the WSR-88D and covering. This worst-case analysis will use the area of the antenna alone (18.7m^2) to determine the reflected power. As the antenna is designed to focus and absorb energy directed at it, this isn't a completely accurate analysis, but is expected to be an acceptable average of the variables mentioned above.

It is assumed that the power is radiated isotropically from the TPS-75 antenna. The TPS-75 will intercept and reflect 28.39 W. Using equation 2-7, where the reflected power is the ERP, the power density at the WSR-88D antenna is calculated to be 1.01E-6 W/m^2. The power received, P_r, is calculated with Equation 2-8:

$$P_r = P_i A_e \qquad (2\text{-}8)$$

$$P_r = \text{Power Received, in Watts}$$
$$P_i = \text{Power Incident, in Watts/meter}^2$$
$$A_e = \text{Antenna Effective Area, in meter}^2$$

The antenna effective area, A_e, for the WSR-88D is given by Equation 1-6:

$$A_e = \frac{g\lambda^2}{4\pi}$$
(2-9)

A_e = Antenna Effective Area, in meter^2
g = Antenna gain, unit less in relation to isotropic antenna
λ = Wavelength, in meter^2

The following values are then used to solve equation 2-8:

G = 19.07 dBi (off-axis gain)
g = 80.72
λ = .1063 m
A_e = .072583 m^2

The power received, P_r ,at the WSR-88D if the TPS-75 antenna is treated as an istropic reflector is 7.35 E-8 W or –41.34 dBm. This value has been determined using a worst-case assumption that 100% of the incident power is reflected isotropically. The power received is not significant enough to cause damage to the WSR-88D, but is enough to be processed and displayed by the WSR-88D as ground clutter.

3

Interference to WSR-88D from TPS-75

The power density, P_d, at the WSR-88D from the TPS-75 is given by equation 3-1:

$$P_d = \frac{gP_T}{4\pi R^2} \qquad (3\text{-}1)$$

P_d = Power Density, in Watts/meter^2
g = Antenna gain, unitless in relation to isotropic antenna
P_T = Transmitted Power, in Watts
R = Range, in meters

Values for equation 3-1 are extracted from TPS-75 specifications in section 1 as:

g = 3981
P_T = 2.8E6 W
R = 1493.5 m

Therefore, the power density at the WSR-88D is 397.68 W/m^2 or 55.99 dBm/m^2. It is important to understand that this is the power density at the TPS-75 frequency, which is 230 MHz above the WSR-88D frequency. Based on information from Sgt Kaulley (as noted in section 1), the TPS-43 bandwidth will be used for evaluation of the TPS-75 power level at the WSR-88D.
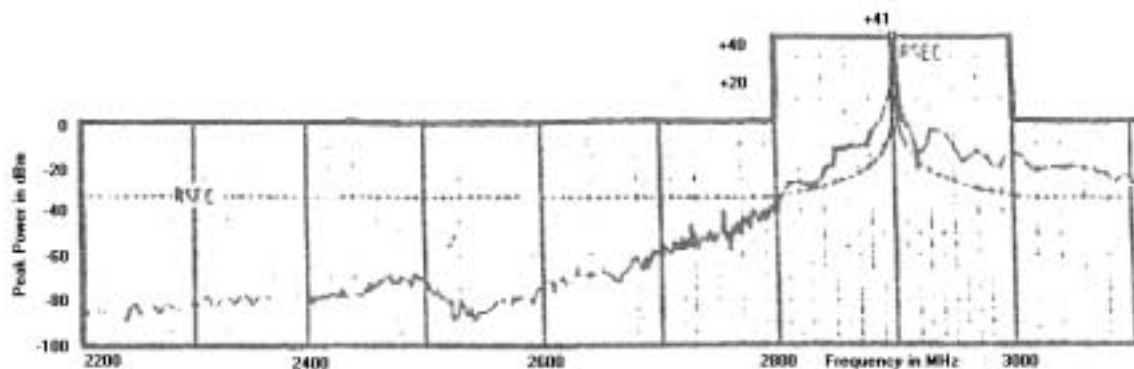

Figure 2 – TPS-43 Spectrum [1]

From figure 2, the relative power loss 230 MHz from the center frequency is approximately 111 dB. The power density, P_d, at the WSR-88D is then adjusted to 3.158E-9 W/m^2.

Assuming the beamwidth listed in the specifications of the TPS-75 is 3dB down from center, when the TPS-75 antenna is at its lowest elevation scan angle of 0.5°, the power density present at the WSR-88D will be no less than 3dB down from the peak power along the beam center.

As shown in figure 1 and discussed in section 2, the elevation angle between the WSR-88D and the TPS-75 is 1.35°. As in section 2, the Antenna factor, A_e , must be adjusted for this angle and is calculated with equation 2-9 to be .072583 m^2. The received power, P_r , at the WSR-88D antenna output is 2.2E-10 W or –66.4 dBm.

The minimum discernible signal (MDS) at the WSR-88D is –112 dBm. Therefore, the power seen at the WSR-88D due to the TPS-75 is 45.6 dB over the MDS which indicates there will be significant interference to the WSR-88D that will be evident on the Principal User Position (PUP) as large strobes of very high reflectivity. This will impact significantly impact the coverage area of the WSR-88D and dramatically degrade the quality of weather data.

4

Interference to TPS-75 from WSR-88D

As calculated with equation 2-7, the WSR-88D will cause a peak power density at the TPS-75 of 1518 mW/m^2. The peak RF field strength at the TPS-75 is calculated with equation 4-1:

$$E = \sqrt{P_d Z_0} \qquad\qquad (4\text{-}1)$$

E	=	Field Strength (Volts/meter)
g	=	Characteristic Impedance of Free Space (120$\pi\Omega$=377Ω)
P$_d$	=	Power Density, in Watts/meter^2

The peak RF field strength is 23.92 V/m. This is approximately one-half the threshold of 50 V/m specified in MIL-STD 461E. The risk of tower equipment bulk cable interference from the WSR-88D is minimal

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Microwave Radiation Levels at the TPS-75

For the purposes of determining the possible effects of the WSR-88D transmissions on personnel at the TPS-75, the average power density is calculated with equation 5-1:

$$P_{avg} = P_{peak} * PRF * \tau$$

(5-1)

P_{avg}	=	Average Power Density, in Watts/meter^2
PRF	=	Pulse Repetition Frequency, in Hertz
τ	=	Transmitted Pulse Width, in seconds
P_{peak}	=	Peak Power Density, in Watts/meter^2

For the WSR-88D the variables are as follows:

PRF	=	1013.51 Hz (PRF 5, Delta C)
τ	=	1.57E-6 seconds (Short Pulse)
P_{peak}	=	1.518 W/m^2

The above values yield an average power density at the TPS-75 of 2.415E-4 mW/cm^2. This value assumes that the WSR-88D antenna is not rotating and is pointed at an elevation angle of 0.5°. This is will not occur operationally and is only possible if the WSR-88D is manually directed by maintenance personnel during off-line diagnostics. In the event that this were to occur, the power density level is still over 4000 times below the FCC maximum exposure level for the general population of 1 mW/cm^2 and over 20000 times below the FCC maximum exposure level for Occupational exposure.

There will be no public or occupational hazard at the TPS-75 from the WSR-88D radar system.

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Microwave Radiation Levels at the WSR-88D

For the purposes of determining the possible effects of the TPS-75 transmissions on personnel at the WSR-88D, the average power density is calculated with equation 5-1 using the following values:

$$\begin{aligned} \text{PRF} \quad &= \quad 275 \text{ Hz} \\ \tau \quad &= \quad 6.8\text{E-6 seconds} \\ P_{peak} \quad &= \quad 397.68 \text{ W/m}^2 \end{aligned}$$

The calculated average power at the WSR-88D caused by the TPS-75 is .0744 mW/cm^2. This is 67 times lower than the FCC maximum occupational exposure limit of 5 mW/cm^2 and 13 times lower than the FCC maximum exposure limit for the general population of 1 mW/cm^2. Additionally the average power density is reduced even more when the TPS-75 antenna is rotating at its operational rate of 6.5 rpm.

There will be no radiation hazard to personnel at the WSR-88D site from the TPS-75. This assumes a peak power at the TPS-75 of 2.8 MW.

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Summary

1. There will be no main beam blockage by the TPS-75 antenna or support structures.

2. The power reflected from the TPS-75 to the WSR-88D will likely appear as ground clutter on the PUP.

3. The power injected in the WSR-88D by the TPS-75 has the potential to significantly impact the WSR-88D's coverage area and dramatically degrade the quality of weather data in the direction of the TPS-75.

4. No bulk cable interference is expected at the TPS-75 from the WSR-88D.

5. There will be no microwave radiation hazard to personnel at the TPS-75 from the WSR-88D.

6. There will be no microwave radiation hazard to personnel at the WSR-88D from the TPS-75 assuming the specifications as detailed in this report.

8

References

1. DeSalvo, Richard G., *EMI and Bioeffects Measurements In Support Of The WSR_88D Site at Camp Humphreys, Republic of Korea*, Joint Spectrum Center Report, April 1996

2. Sirmans, Dale, Calibration of the WSR-88D" OSF Internal Report, Sep 30, 1992

3. Sirmans, Dale and Paul Bontempi, WSR-88D Radiation and Biological System Considerations, OSF Internal Report, 1994.

MSgt Byrnes and SSgt Kaulley of the 728th ACS of Eglin, AFB FL, provided specifications of the TPS-75. They can be contacted at:

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